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Ecology of soil fauna of Mediterranean desert ecosystems in Egypt

I. — Summer populations of soil mesofauna associated with major shrubs in the littoral sand dunes

BY

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INTRODUCTION

Soil zoology has made remarkable progress in the last twenty years. Most of this progress was achieved by careful investigations of soil fauna populations in forest and gressland ecosystems. Studies on the ecology of populations of soil animals in deserts are very few in comparison so that very little information is given about soil fauna in desert ecosystems in modern texts on soil zoology and soil ecology. This situation has been recently improved, however, by the initiatives produced by the recent trend of studying ecosystems in their entirety. It became apparent that the decomposer part of ecosystems is the least known. Soil fauna in deserts, it was realized, may play a decisive role in breakdown of litter in desert ecosystems where water is in short supply and where micro-organisms remain dormant most of the time, but where some groups of decomposer soil animals may remain active even in the hot dry season, continuing their activity of chewing and triturating litter into a fine powder mixed with digestive enzymes ready to decompose organic matter in the presence of moisture. Moreover, in the case of desert ecosystems in particular, large amounts of litter accumulate without being decomposed because of the dry climate which prevents rate of decomposition to keep up with rate of litter production. This accumulation constitutes a blocking of transfer of organic and inorganic nutrients to the soil and a bottle-neck in the cycling of matter, and eventually, loss of

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fertility and decline in plant productivity whether for grazing or crop production. If certain areas of desert regions are to be reclaimed for agriculture and human settlement — and coastal deserts are of prime importance in this respect (GHABBOUR, 1976) — due attention must be given to the decomposer part of the ecosystem in order to understand its dynamics with the view of increasing its efficiency, thereby minimizing the need to use artificial fertilizers, and, consequently, reducing costs of reclamation and maintenance of soil fertility by mobilizing the natural autochthonous biotic elements in recycling the already available nutrients. It may be possible, by using the proper management techniques to be learned from study of the ecology of soil fauna, to encourage soil fauna to accelerate their activity and help in recycling of nutrients at rates faster than those obtaining under unmanaged conditions. To achieve this, the conditions of life of soil fauna populations in deserts and their ecological relations should be well understood.

The Mediterranean coastal desert of Egypt lying between Alexandria and Salloum (at the Egyptian-Libyan border) has special features and a special history of its own. It extends for about 500 Km and is favoured by a relatively high winter rainfall (about 180 mm/year) just enough to help grazing and rain-fed dry farming activities. It thus has better biological potentiality for reclamation and human settlement, together with oases of the inner deserts, than the rest of the Egyptian deserts. History of land-use in this region in the last 2000 years was reviewed by KASSAS (1972) who concluded that neglect, and not lesser rainfall, was the main factor leading to the degradation of this area (known as Mariut or Mareotis in its eastern part) from its previously prosperous state in Graeco-Roman times. Continued uncontrolled cutting and grazing following in the wake of armies and warring parties from the 4th to the 11th centuries A. D., have caused reduction of perennial plant cover, soil erosion and destruction of ancient soil and water conservation works. In the 20th century, efforts have been made to establish fig, olive and other cultivations practised by the bedouins by dry farming. Nevertheless, grazing by sheep and goats remains the principal form of land use at present.

This coast is now regarded as a natural outlet for releasing the population pressure in the Nile Valley and Delta which has now become congested with a population of 39 million people seeking food and shelter in an area of 2.31 million hectares, i. e. 0.06 ha/person; whereas the individual's share in 1907 was 0.40 ha. Therefore, several development schemes have been planned for the rehabilitation of this area to make it more productive and suitable for the settlement of larger numbers of citizens. These schemes include: the Suez-Mediterranean oil piepline « Sumed » which will end at Sidi Kreir, oil prospecting at the Alamein oil-fields and another oil-port at Alamein, a nuclear reactor at Sidi Kreir for desalinization of sea water for purposes of agriculture, a canal from Alamein to the Qattara Depression for production of hydroelectric power for industry, sale of the coastal land for recreation and tourism projects, above all these, irrigation by Nile water of large tracts of desert. The environmental consequences of these projects are discussed by IMAM (1975).

In many parts of the world, natural and semi-natural coastal desert areas are being developed in a similar manner. There is therefore great need for developing the scientific bases for the rational use and conservation of resources of such areas, and for making the appropriate environmental impact assessments based on a wide knowledge with reliable data and parameters.

THE STUDY AREA

The present paper reports some of the first results obtained in the study of soil fauna within the framework of « SAMDENE » Project (Ayyad and Ghabbour, 1977). This project aims at providing the decision-maker and the environmental manager with the sound ecological bases so as they can make better long-term evaluations of their plans without undue wastage of resources. In order to achieve this and to obtain a high degree of predictive ability, the techniques of mathematical modelling, systems analysis and simulation will be used for understanding material cycling and energy flow in the ecosystem, and of spatial and temporal changes in biota in relation to environmental variations in the Mediterranean desert ecosystems of northern Egypt, west of Alexandria (the Mariut area), for prediction of probable environmental effects resulting from various land use practices and proposed manipulations.

The area of study (Fig 1) has been described from the standpoints of geology and geomorphology by Philip (1955), Shukry *et all.* (1956), Abdel-Mogheeth (1968); climatology by Ali (1952), Arvidson and Hellström (1955), Migahid and Ayyad (1959), Ayyad (1971); hydrology by Paver and Pretorius (1954), Abdel-Rahman *et al* (1965); soils by Abdel-Samieh *et al* (1956), Harga (1967) and plant ecology by Migahid and Ayyad (1959), Tadros and El-Sharkawy (1960), Ayyad (1973). The ecology of some common lizards at a site 19 km west of Alexandria under similar bioclimatic and pedological conditions was studied by Hussein *et al.* (1969 and 1974). A review of the history of land use in Mariut in the past 2000 years analysing stories of failures and successes was given by Kassas

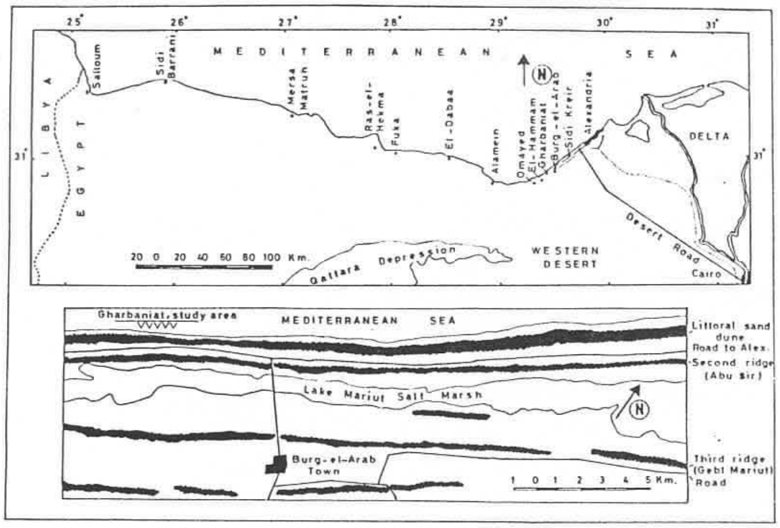

Fig. 1. — Map of the northwestern coastal Mediterranean region of Egypt showing localities mentioned in the text, and map of the Burg-el-Arab and Gharbaniat area showing the series of ridges and depressions.

(1972). His conclusion is that horticulture (mainly olives) is much more productive and worthwhile from an ecological point of view than barley cultivation. Prospects for agricultural and livestock development of the region were studied in detail by a United Nations team of experts (UNDP/FAO, 1971).

The eastern part of this coastal region (viz. between Alexandria and El-Alamein) is characterized by prominent topographic features: a series of parallel ridges parallel to the sea coast and alternating with a series of depressions. Accordingly, two sets of habitats may be distinguished, one on ridges and the

PHOTO 1. — General view of stand 16, dominated by *Ammophila arenaria* and *Pancratium maritimum* with *Lycium europaeum* the cohabiting shrub. The area is used for quail trapping by the small tent-like bundles of Grass.

PHOTO 2. — A shrub of *Lycium europaeum* in stand 16. The accumulated litter can be seen under the canopy. This species of shrub has a high populations density of sand roaches in the soil under its canopy.

PHOTO 3. — A shrub of *Lygos raetam* on the landward slope of the littoral sand dune. This shrub has a high population density of total soil mesofauna in the soil under its canopy.

PHOTO 4. — A shrub of *Thymelaea hirsuta* on the crest of the littoral sand dune. Shrubs of this species have usually upright diffuse branches but some individuals may have canopies touching the ground.

other on depressions. Ridge habitats may be further distinguished into the habitat of the littoral ridge, which is overlain by accumulations of snow-white loose calcareous sand grains (the oolitic limestone of the littoral sand dunes), and that of the inland less calcareous consolidated ridges. Habitats of depressions are differentiated according to the depth of the water table and salinity level into saline and non-saline depressions (AYYAD, 1973). These four major types of habitats are physiographically, vegetationally and faunistically distinct. These distinctions are reflected in forms of land use of these habitats (AYYAD and GHABBOUR, 1977).

The findings reported here pertain to soil fauna investigations in the littoral sand dune site at Gharbaniat, 5 Km west of Burg-el-Arab (53 Km west of Alexandria). This dune lies in an ENE/WSW direction and is about 500 metres across. Its highest elevation is 20-21 m a.m.s.l. and the average elevation is 10-17 m. The crest of the dune is nearer to its southern edge, i.e., most of the dune surface is north-facing and exposed to direct action of wind and sea. The littoral sand dune habitat is dominated by *Ammophila arenaria, Ononis vaginalis, Echinops spinosissimus* and *Crucianella maritima.* Major shrub species are *Lygos raetam, Thymelaea hirsuta* and *Lycium europaeum.* The vegetation was analysed by AYYAD (1973). Plant nomenclature is according to TÄCKHOLM (1974). Shrubs of the above mentioned three species are the larger shrubs present on the dunes (see photos), preliminary tests showed that soil animals were concentrated under these shrubs. Very few soil animals, apart from ants and wandering tenebrionid beetles, were found in the open spaces between shrubs.

TABLE I

Meterological data of the Burg-el-Arab area, (fifteen years averages from 1950 to 1964) *, from AYYAD (1973)

Month	Air Max.	Température Min.	(°C) Mean	Relative humidity (%)	Evaporation (mm/day)	Wind velocity (km/h)	Rainfall (mm)
July	29.2	21.6	25.2	71.2	8.3	15.4	0.0
August	30.0	22.4	26.0	72.0	9.0	14.0	0.0
September	28.3	21.4	24.6	69.7	8.4	11.5	0.7
October	27.2	17.3	21.6	60.5	7.3	10.2	22.1
November	20.3	14.0	18.6	66.1	6.8	13.6	28.6
December	19.5	10.2	14.2	65.3	6.1	16.0	43.5
January	18.5	8.4	13.2	65.4	5.8	16.2	38.4
February	18.7	9.0	14.0	63.7	6.7	15.8	24.5
March	21.3	10.8	15.4	62.8	7.2	16.8	7.3
April	22.5	12.4	17.6	64.2	7.5	15.5	2.7
May	25.4	15.4	20.0	65.8	8.1	14.3	1.1
June	27.8	19.2	23.6	70.0	7.2	15.0	0.0
Yearly average	24.0	15.2	19.5	66.4	7.4	14.5	168.9 total

* It is noted that in this and in the following Tables climatic data are arranged from July of one year to June of the next year so as to show the effects of climate in a bioclimatic time unit and not in a chronological unit.

Climate.

According to the conclusion of the UNDP/FAO report, (1971), the climate prevailing along the northwestern coast of Egypt can be qualified as « arid Mediterranean with mild winters ». It is one of the mildest of the Mediterranean Sea. Winter temperatures are higher than in any other part of the Mediterranean coast; frosts are not met with. Summer temperatures never exceed critical values. Evaporation is reduced by not too hot summers and by the rather high moisture content of the air. All these favourable conditions are unfortunately offset by the scarcity of rainfall that places the region at the limit of the Saharian climate. The following Table gives records of climatological elements for Burg-el-Arab (7 Km SE of Gharbaniat, the nearest meteorological station) after AYYAD (1973).

TABLE II

Mean number of rainy days R//x mm at Alexandria (53 km E of Gharbaniat) after UNDP/FAO (1971). Years: 1951-1965

	J	A	S	O	N	D	J	F	M	A	M	J	Annual mean
R//0.1 mm......	0	0	0.3	3.9	7.2	10.9	10.1	7.3	5.3	1.6	1.1	0	47.7
R//1 mm.......	0	0	0.2	2.5	4.3	7.0	6.7	4.8	2.5	0.7	1.1	0	30.2
R//5 mm.......	0	0	0	0	0.7	1.9	3.9	2.6	2.0	0.4	0.2	0	11.7
R//10 mm......	0	0	0	0	0.3	0.8	1.9	1.4	0.7	0.1	0	0	5.2

The following Tab. III shows the severe fluctuations in rainfall from year to year. There is a difference of 200 mm (more than the yearly average) between the 1964-65 and the 1965-66 seasons.

TABLE III

Rainfall at Burg-el-Arab : 1964-1968, after UNDP/FAO (1971)

Year	J	A	S	O	N	D	J	F	M	A	M	J	Total
1964-65............	0	0	0	0	56.5	98.0	66.0	1.5	3.0	13.0	0	0	238
1965-66............	0	0	0	10.5	1.0	3.0	0	21.0	3.0	0	0	0	38
1966-67............	0	0	0	0	142.5	0	32.9	9.0	8.0	0	0	0	192
1967-68............	0	0	0	1.4	28.7	15.9	20.6	16.7	4.0	0	0	0	87

The following Tab. IV gives more climatic data from the Alexandria station (53 km E of Gharbaniat), the nearest station belonging to the same bioclimatic zone of Gharbaniat with more detailed records than the Burg-el-Arab station.

TABLE IV

Climatic data of Alexandria, pertaining to moisture, sunshine and wind speed. Years: 1951-1965, after UNDP/FAO (1971)

	J	A	S	O	N	D	J	F	M	A	M	J	Annual mean
Mean relative humidity %													
at 0600 UT............	69	70	67	72	76	86	80	77	70	67	65	68	72
at 1200 UT............	61	60	56	54	54	56	54	52	51	49	51	58	55
Saturation deficit mm Hg													
at 0600 UT............	7.7	8.1	8.3	5.8	3.8	1.6	2.0	2.4	3.8	5.2	6.9	7.6	5.2
at 1200 UT............	12.1	14.0	13.1	13.1	10.0	7.5	7.0	7.6	8.7	10.5	11.7	11.7	10.6
Evaporation (Piche) mm/d-1................	5.3	5.4	5.7	5.1	4.4	3.9	3.9	4.5	5.1	5.4	5.8	5.5	4.5
Bright sunshine duration % of possible..........	86	90	90	87	78	66	68	71	75	82	80	84	80
Average wind speed km/hr.................	15.9	15.7	14.4	12.6	13.0	15.9	17.0	17.2	18.2	16.7	15.4	16.5	15.7

Cloudiness is greater along the coast than inland. The difference between the coast and Cairo is 10 % in winter and spring and 5 % for the whole year. Wind speed decreases in May and June, but July is windy. The end of the summer records many calm days and the average speed drops to 15 km/hr (4 m/s).

Maximum wind velocities are expected to occur :

more than 100 km/hr - 2.2 times in 10 years,
more than 80 km/hr - 18 times in 10 years, and
more than 60 km/hr - 58 times in 10 years.

Northwest winds prevail with a frequency of 30-40 % and southwest winds 13-19 %.

TABLE V

Climatic indices, after UNDP/FAO (1971)

	P mm/y	M°C	m°C	Gorszynsky	Emberger
Alexandria.................	181	30.8	9.2	17.7	29
El-Dabaa..................	141	29.8	7.3	19.7	21

Soils :

AYYAD (1973) gave the following values for results of analysis of the oolitic limestone soil of the littoral sand dune habitat, at the Gharbaniat site. The average pH value is 8.5.

TABLE VI

Results of analysis of littoral sand dune soil at Burg-el-Arab in different physiographic categories (I, active dunes; II, partly stabilized dunes; III, stabilized dunes, IV, sand shadows), after AYYAD (1973)

Type of Analysis	Physiographic category			
Mechanical analysis	I	II	III	IV
Diameter of particles (mm)				
2.0-1.0	0.3	0.5	0.3	0.2
1.0-0.5	48.5	45.6	43.2	48.0
0.5-0.25	41.4	43.0	44.7	40.5
0.25-0.1	9.1	9.5	10.1	9.1
0.1-0.05	0.3	0.9	0.9	1.5
0.05-0.002	0.1	0.2	0.5	0.5
less than 0.002	0.1	0.1	0.1	0.1
Organic matter (%) depth.				
0-25 cm	0.81	0.50	1.64	1.41
25-50 cm	2.42	2.28	1.88	1.08
Nitrogen (%)				
0-25 cm	0.015	0.019	0.019	0.019
25-50 cm	0.014	0.017	0.014	0.018
Calcium carbonate (%)				
0-25 cm	69.8	69.0	68.8	67.0
25-50 cm	67.3	67.3	71.2	65.7
Salinity (m-equiv./100 gm)				
0-25 cm	14.7	12.7	12.3	10.1
25-50 cm	13.5	10.1	11.3	10.9

It is seen that 90 % of the soil particles lie within 0.25-1.0 mm size range and that calcium carbonate constitutes 67-71 % of particles. Organic matter tends to increase with stabilization of the dunes (in the landward side). Nitrogen also shows the same trend. It is to be noted that analyses were made for soil samples taken from spots in the open spaces between shrubs. In the presents investigation, further analysis is to be undertaken for soil samples from under the canopies of shrubs.

TABLE VII

Stands from which shrubs were selected for sampling soil fauna by the sieving method

Stand	Shrub	Location	Dominant Vegetation
2	*Lygos*	southern edge of dune.	*Thymelaea hirsuta* group.
14	*Thymelaea*	middle part of dune.	Transitional area.
16	*Lycium*	northern edge of dune.	*Pancratium maritimum* group with *Ammophila arenaria*.

The stand number is the one used in « SAMDENE » vegetation analysis studies.

METHODS

Since soil animals were found in the preliminary tests to concentrate under the shrubs where litter could accumulate and protection from excessive heat and evaporation was provided, sampling was made from under the three aforementioned shrub species. Shrubs of *Lygos reatam* are more abundant at the crest and nearer to the south-facing side of the dune, those of *Thymelaea,* at the crest and those of *Lycium* at the north-facing side (Tabl. VII).

The flotation method by the use of $MgSO_4$ solution of 1.2 specific gravity was tried first, but it was found inefficient in extraction in proportion to expenditure of effort and material. The sieving method was therefore used regularly since February 1975, once per month. The sparseness of vegetation did not allow for a more frequent sampling. This method was adapted from that used in Tunis (Tunisian Presaharan Project, 1974). A shrub of average size is selected (in some cases from the stand itself and in most other cases from similar stands along the dune) and the whole soil covered by the canopy of that shrub is excavated and passed through a sieve of 50 cm diameter which allows the passage of particles smaller than 1.1 mm. All the litter and animals remaining in the sieve are collected and placed in tight bags. Excavation and sieving are continued until no litter or animals are visible by further digging in the area covered by the shrub canopy. This is usually at a depth of 30 cm, but depths of 40 and 60 cm were reached in some cases. The mean radius of the shrub is determined by half the average of the largest and smallest diameters of that shrub. Diameter of shrubs ranged from 110 cm to 210 cm. Distinction was made to separate samples from the windward (NW) and leeward (SE) sides of each shrub, but there was no indication to justify division of the samples into strata according to depth. The litter samples obtained from sieving were examined under a binocular microscope (magnification x 100), either immediately upon return to the laboratory or they were kept in the refrigerator at 5° C until examined a few days after collection.

This method gave much higher yields of species and of individuals than the flotation method. It is believed from the past year's experience that the sieving method gives fairly satisfactory quantitative estimates of the soil mesofauna under shrubs because very few animals can escape being detected. Some animals smaller than 1.1 mm in diameter were even detected because they were clinging to the litter. Only flying insects (which are not true soil dwellers) and very small animals can escape. In order to correct the loss of the last group, flotation of intact soil samples is also continued.

Each animal found in the binocular examination or by flotation is picked, sorted and stored in 70 % ethyl alcohol.

Soil samples from the surface and from depths of 20 cm and 50 cm from under the canopy of the same shrubs are also collected for determination of soil moisture and other soil characteristics. Soil moisture is determined by drying in an oven at 105° C for 24 hours.

RESULTS

Some of the results obtained from January to September 1975 are reported in Tables VIII-XVI. Table 8 gives counts of openings of ant nests (*Messor* spp.) made once per month in quadrats of an area of 0.26 ha in the same stands from which sieving for soil mesofauna was done under the shrubs. Therefore, these stands are given the names of the shrubs. The counts of ant nest openings indicate that there was intense nest building activity in December, February and March. Nest bulding activity, as a matter of fact, was begun by the ants in November 1974 when it was decided to lay these quadrats. Ants were observed actively foraging in summer, except in August. They nest in the open spaces between shrubs and very rarely under their canopies. In a few cases, they take advantage of rock crevices to start their nest building. In one case, a colony was found in February in moist soil overlying a large stone which created something like a perched water table. The highest number of nest openings is in the *Lygos* area, probably because of its leeward aspect protected from strong winds. The shallow-soiled and exposed north facing *Lycium* area is devoid of nests. The low numbers of nest openings in January may be due to obliteration by rain which fell heavily in that month. *Messor* workers are of five sizes; they harvest seeds according to their sizes. They collected seeds of *Jasonia candicans* in February and of *Elymus farctus* in May.

TABLE VIII

Openings of ant nests *(Messor)*. Number of openings in quadrat of 0.26 ha

Month	Stand		
	2	14	16
December 74	79	51	0
January	2	2	0
February	70	23	0
March	59	23	0
April	11	0	0
May	2	0	0
June	4	10	0
July	6	2	0
August	2	0	0
September	3	1	0
October	5	10	0

Table IX shows the numbers of species and systematic positions of mesofauna collected under each shrub species in the study period reported here. The term mesofauna is used here to denote the size range of animals that were caught by the sieving method, which excludes microscopic groups such as protozoa, nematodes and most mites (microfauna) and soil-dwelling lizards and rodents (macrofauna). Most of the species collected are detritivores. Predators include Myriapoda, spiders, pseudoscorpions, antlions, carabid beatles, a therevid larva and probably a noctuid larva. The order with the largest number of species is Colepotera. Table X shows the number of species and population density under shrubs in the windward and leeward directions. Higher population densities are recorded, on the average, under *Lygos*, followed by *Thymelaea* and *Lycium* but the reverse holds true for sand roaches. In early September 1975, bedouins disturbed shrubs on the littoral dune at Gharbaniat and elsewhere along the coast by excavating soil under them, setting trap nets for quail and redepositing the excavated soil. This setting of quail traps is the main reason why shrubs of the littoral dunes are not cut down if fig cultication is not practised. Samples collected from under those disturbed shrubs are designated « Sept. 1 » and are compared with samples taken two weeks later from similar but undisturbed shrubs (confirmed by absence of trap nets) which are designated « Sept. 2 ». Sept. 1 samples show the lowest population densities. Thus the impact of this

Systematic list of species collected in the area (by sieving and otherwise)

- Isopoda, Oniscoidea
    - *Agabiformes lentus* (B.L.)
    - *Porcellio albinus* (B.L.)
- Dictyoptera, Blattoidea, Polyphagidae
    - * *Heterogamia syriaca* Sauss.
- Rhynchota, Heteroptera, Cydnidae
    - *Sehirus melanopterus* H.-S.
    - *Macroscytus brunneus* F.
    - Myodochidae (Lygaeidae)
        - *Emblethis verbasci* F.
- Neuroptera, Myrmeleonidae (nymphs)
    - *Cueta* sp.
- Coleoptera, Carabidae
    - *Bradycellus lusitanicus* Dej. ?
    - *Cymindis suturalis* Dej. var.
    - Scarabaeidae
        - *Psammobius porcicollis* Ill.
    - Melolonthini (larvae)
    - Cetonini (larva)
    - Tenebrionidae
        - *Crypticus murinus* All.
        - *Dendarus piceus* Ol.
        - *Machlopsis crenatocostata* Pioch.
        - *Pimelia* sp. (larvae)
        - *Psammoica lucida* Sol.
        - *Stenosis torre-tassoi* Koch
    - Helopini (larva)
    - Antichidae
        - *Hylophilus* ?
    - Curculionidae
        - *Otiorhynchus* sp.
    - Hymenoptera, Formicidae
        - *Camponotus maculatus* F.
        - *Messor barbarus* F.
        - *Messor barbarus* var. *aegyptiacus*
        - *Messor semirufus*
- Diptera, Ceratopogonidae (larva)
    - Therevidae (larva)
    - Bibionidae (larva)
- Arachnoidea, Opiliones
    - *Phalangium savignyi*
- Araneae, Agelenidae
    - Dysderidae
    - Gnaphosidae, Laronieae
    - Salticidae
- Acari, Prostigmata, Trombidiidae
- Pseudoscorpiones
    - *Olpium kochi* Simon
- Myriapoda, Chilopoda, Geophilomorpha
    - *Geophilus* sp.

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* Prof. W. KÜHNELT (priv. corr.) writes that the specimens are intermediary between *syriaca* Sauss. and *africana* L., but the gives the name *syriaca* to the specimens from Gharbaniat.

TABLE IX

Total number of species of mesofauna collected from under major shrubs at the Gharbaniat site

Stand	2	14	16
Shrub	*Lygos*	*Thymelaea*	*Lycium*
Isopoda	2	1	1
Thysanura	—	—	1
Dictyoptera	1	1	1
Rhynchota	1	1	—
Neuroptera	2	2	1
Diptera			
(larvae)	2	3	4
(adults)	—	1	—
Coleoptera			
(larvae)	4	5	3
(adults)	15	8	10
Hymenoptera (ants)	2	2	2
Spiders	3	1	1
Pseudoscorpions	1	1	1
Centipedes	2	—	1

TABLE X

Monthly variation in number of species (NS) and total population density of soil mesofauna (TPD, individuals/m²), population density of sand roaches *(Heterogamia)* (PDSR, individuals/m²) extracted by sieving at the windward (W) and leeward (L) sides under the canopy of shrubs, also monthly variations in sand roach dry weight biomass (SRDWB, mgm/m², calculated). Sept. 1 row shows results of sampling under shrubs disturbed for quail trapping. Sept. 2 shows sampling results from undisturbed shrubs a fortnight later. February sampling was taken at end of January 1975

Month / Shrub	*Lygos*		*Thymelaea*		*Lycium*		Average*
Side	W	L	W	L	W	L	
February							
NS	6	16	7	8	7	7	—
TPD	106	490	35	99	51	43	137
PDSR, Ad	2	11	1	13	8	8	10
Ny	0	0	12	9	15	19	9
SRDWB, Ad	318	1 978	243	2 427	5 288	1 479	1 789
Ny	0	0	43	34	55	71	34
March							
NS	4	5	3	7	1	1	—
TPD	23	46	7	53	13	22	27
PDSR	17	23	0	35	13	22	18
SRDWB	2 362	3 139	0	4 781	1 778	3 025	2 514

Month / Shrub	*Lygos*		*Thymelaea*		*Lycium*		Average*
Side	W	L	W	L	W	L	
April							
NS	6	6	7	10	4	5	—
TPD	24	14	16	36	26	31	26
PDSR	4	7	5	16	22	22	13
SRDWB	616	1 046	799	2 395	3 334	3 333	1 919
May							
NS	21	17	1	6	11	3	—
TPD	161	30	10	15	57	25	50
PDSR	15	5	0	6	21	21	11
SRDWB	3 344	1 232	0	1 295	4 751	4 753	2 562
June							
NS	8	8	0	16	3	7	—
TPD	40	37	0	144	13	29	44
PDSR	10	1	0	3	10	12	6
SRDWB	1 873	208	0	477	1 912	2 151	1 103
July							
NS	8	15	3	8	8	6	—
TPD	16	57	4	27	48	66	36
PDSR	7	19	1	8	15	41	15
SRDWB	1 230	3 280	226	1 355	2 657	7 085	2 639
August							
NS	12	11	6	14	3	9	—
TPD	47	43	6	137	8	9	42
PDSR, Ad.	8	19	2	2	0	1	5
Ny.	0	0	0	76	0	0	13
SRDWB, Ad.	1 687	3 894	320	481	0	179	1 094
Ny.	0	0	0	283	0	0	47
September 1							
NS	8	7	1	4	7	7	—
TPD	42	49	2	15	21	4	29
PDSR	6	3	0	4	4	0	3
SRDWB	1 126	675	0	838	838	0	579
September 2							
NS	15	10	13	16	6	15	—
TPD	64	71	43	69	14	31	48
PDSR	2	4	4	12	6	7	6
SRDWB	312	780	792	2 374	1 226	1 403	1 148
Averages for shrubs							
TPD	80		44		30		*51*
PDSR	10		13		17		*13*
SRDWB	1 775		1 145		2 673		*1 865*

Ad. = adults, Ny. = nymphs.

* Averages for shrubs excluding Sept. 1 data.

** No significant difference (*t* test) between Sept. 1 and Sept. 2, samples in sand roach population density, but $X^2_{(3)} = 13.22$, for which p lies between 0.05 and 0.02. The difference thus reaches the level of significance.

annually recurring disturbance on the soil fauna can be shown. The Sept. 1 samples are not included in the calculation of average. Although there is no statistically significant difference between Sept. 1 and Sept. 2 population densities of the soil mesofauna as a whole, the X^2 test shows a significant difference in the population densities of sand roaches (Tabl. X and XI).

Table XII shows monthly breakdown of catches into trophic groups. The detritivores are conveniently divided into sand roaches and « other

TABLE XI

Statistical significance of differences between soil mesofauna population densities in relation to shrub species, wind direction and through time

Directions
    Windward versus leeward *
        Lygos ns., *Thymelaea* 3, *Lycium* ns.

Plant pairs
        Lygos versus *Thymelaea* ns, *Lygos* versus *Lycium* ns,
        Thymelaea versus *Lycium* ns, Sept. 1 versus Sept. 2 ns,

Seasons
1. Feb. - Apr. versus May - July ns
   May - July versus Aug. - Sept. 2 ns
2. Feb. - Mar. versus Apr. - June ns
   Apr. - June versus July - Sept. 2 ns

* *t* test and X^2 test, *t* test in all other cases.
ns = not significant.
3 = p from 0.01 to 0.01.

TABLE XII

Monthly breakdown of soil mesofauna into trophic groups (as percentages of total numbers extracted)

Month	Sand roaches*	Ants	Other detritivores	Predators
February	18.3	0.4	76.5	2.3
March	64.9	0	33.3	1.8
April	41.2	0	57.2	1.6
May	17.5	1.0	79.8	2.0
June	13.7	0.5	83.1	1.9
July	38.5	1.9	49.1	10.6
August	42.7	0.6	51.2	5.6
September 1	9.9	2.5	83.5	4.1
September 2	11.4	19.5	63.4	5.7
Average	27.4	3.4	65.5	3.7
Standard error	0.9	0.4	1.0	0.4

* Number of egg cases = 9.5 % of total sand roach population *(Heterogamia)*, standard error = 0.6.

detritivores » (isopods, coleoptera, etc.) because sand roaches constitute a conspicuous species. Ants, although less numerous under the shrubs, increased conspicuously in the Sept. 2 sampling. They were of the species *Camponotus maculatus*. Predators are seen to increase in summer due to the appearance of antlions and pseudoscorpions. The effect of the September disturbance is not marked in terms of trophic group composition. Some species classed as « other detritivores » may supplement their diet by being predators, fungivores, root feeders or granivores.

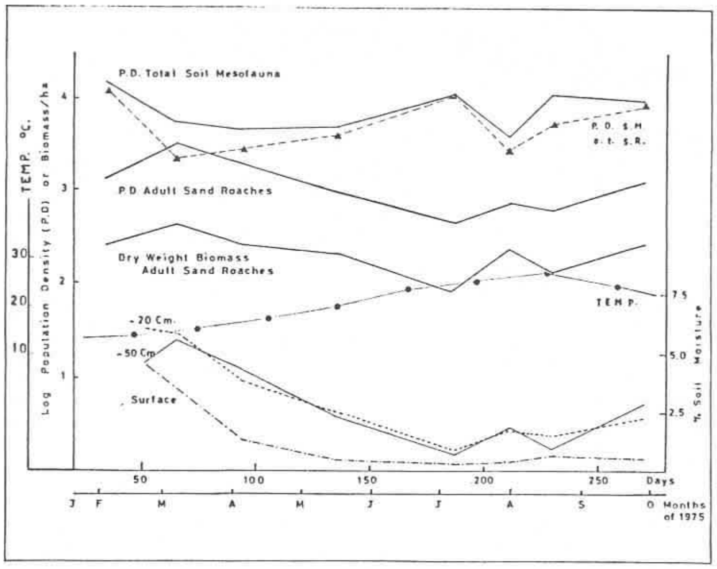

FIG. 2. — Relationship between log population density of total soil mesofauna, per hectare, log population density of adult sand roaches per hectare and log dry weight biomass of adult sand roaches per hectare (upper 3 lines) and soil moisture content at the surface, at — 20 cm and at — 50 cm (lower three lines) from February to September at the Gharbaniat littoral sand dune site. The data for the month of September are those taken from undisturbed shrubs. The figure also shows monthly variations in log population density of soil mesofauna other than sand roaches, also per ha (dashed line with triangles, P.D. S.M.o.t. S.R.) and variation of mean monthly temperature (full line with closed circles). Values for this line are from Table I and are plotted against the 15th day of each month.

Tables XIII and XIV describe the situation as regards population density and dry weight biomass of sand roaches. Table XIV gives an extrapolation of population density of soil mesofauna and of sand roaches, and of dry weight biomass of sand roaches, per hectare; this is calculated on the basis of the percentage cover known for each of the three shrub species. Table XV gives results of soil moisture determinations. These determinations show that soil moisture falls in May and June but rises again in July, August and September, although there is no rain. It is retained at a depth of 50 cm and remains till October. This moisture gain by the soil is associated with a rise in the summer population density and dry weight biomass of sand roaches/ha (Tabl. XIV, Figs. 2 and 3) and the appearance of large numbers of sand roach nymphs in August. Thus, sand roaches at the Gharbaniat littoral sand dune site have at least two reproductive seasons, one in January/February and the other in August.

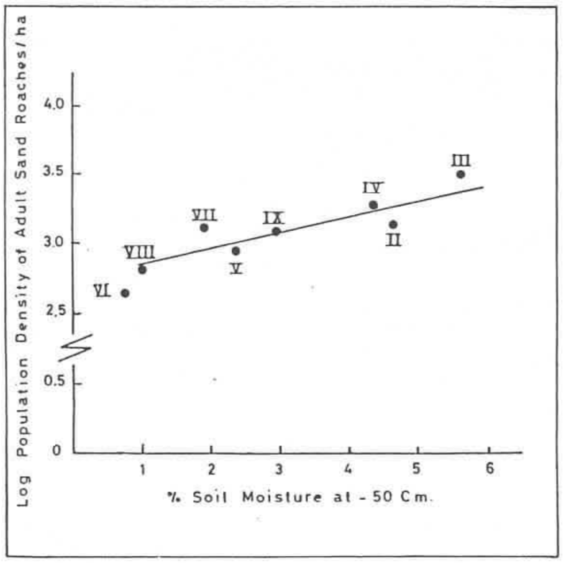

FIG. 3. — Regression line for relationship between log population density of adult sand roaches (*Heterogamia*) per hectare and soil moisture content at — 50 cm. The equation is y (log population density/ha) = 0.113 x + 2.753, where x = soil moisture levels between 1 and 6 % at — 50 cm, for N = 7. The standard error of the equation (i.e. the variance) is 0.0966. Numerals on the dots represent months of the year.

Table XVI gives the rank correlation values for the logarithm of population density of adult sand roaches and the logarithm of their dry weight biomass on one hand with the soil moisture at the depths of — 20 cm and — 50 cm on the other hand. It appears that the highest correlation is between log population density and moisture at — 50 cm. It is in this case + 0.80. On the basis of this, Fig. 3 was drawn to show the regression line of these two variables. The regression equation is $y = 0.113\ x + 2.753$, where y is log population density/ha of adult sand roaches and x soil moisture at — 50 cm. The standard error for this equation (i.e. the variance of the points around the line, or the standard deviation) is 0.0966. This regression equation applies to soil moisture levels at — 50 cm between 1 % and 5.6 %. At levels lower than 1 % (as in June) the line inflects downwards sharply, with a slope corresponding to $A = 1.397$. This shows that sand roaches depend very much on the soil moisture at a depth — 50 cm. This regression line is now useful to estimate the impact of setting quail traps. According to the equation the population density at the observed average soil moisture of 2.36 % at — 50 cm should be 1050/ha, actually it was only 694, so that the population density is reduced by about 34 %.

TABLE XIII

Population structure of sand roaches *(Heterogamia)*. Percentages of sand roach adults, nymphs and egg cases * collected, and monthly variations in dry weight biomass **

Month	Adults %	Nymphs %	Egg cases %	Average dry weight/individual for adults in mgm	no. of specimens used for dry weight determination
February 75	52	48	1	187	10
March	100	—	8	137	10
April	100	—	15	151	10
May	100	—	18	224	10
June	100	—	28	184	7
July	100	—	6	174	6
August	33	67	6	204	10
September 1	100	—	—	—	—
September 2	100	—	32	199	10

* As percentage of total population of adults and nymphs. — Average dry weight of nymphs as determined for 40 nymphs collected in Aug. = 3.72 mgm, i.e. ratio of adult average dry weight to nymph = 50 : 1.

** Calculated by drying at 67° C for 48 hours and keeping over $CaCl_2$ for 5 days.

*** All adults were females except in July and August when about 6 % of the adult population were males.

TABLE XIV

Monthly variations in total population density of soil mesofauna (TPD, individuals/ha), population density of sand roaches *(Heterogamia)* (PDSR, individuals/ha) and sand roaches dry weight biomass (SRDWB, gm/ha) obtained by extrapolation based on percentage cover of each shrub species

Month	Shrub			Total
	Lygos	*Thymelaea*	*Lycium*	
% cover	0.27	1.36	0.11	1.74
February				
TPD	5 612	9 096	516	15 221
PDSR, Ad	166	971	199	1 336
Ny	0	280	186	466
SRDWB, Ad	31	181	37	249
Ny	0	5	1	6

Month	Shrub			Total
	Lygos	*Thymelaea*	*Lycium*	
% cover	0.27	1.36	0.11	1.74
March				
TPD	929	4 103	193	5 225
PDSR	542	2 373	193	3 108
SRDWB	74	325	26	426
April				
TPD	654	3 535	314	4 503
PDSR	148	1 437	243	1 828
SRDWB	22	217	18	257
May				
TPD	2 577	1 701	447	4 726
PDSR	276	374	233	883
SRDWB	62	88	52	202
June				
TPD	1 039	9 803	229	11 070
PDSR	152	175	116	444
SRDWB	28	32	22	83
July				
TPD	976	2 120	630	3 726
PDSR	350	617	308	1 275
SRDWB	61	108	54	222
August				
TPD	1 220	9 776	82	11 078
PDSR, Ad.	369	267	4	640
Ny.	0	5 081	0	5 081
SRDWB, Ad.	70	50	11	131
Ny.	0	19	0	19
September 1				
TPD	1 221	1 144	382	2 747
PDSR	122	286	286	694
SRDWB	24	57	57	138
September 2				
TPD	1 814	7 572	247	9 634
PDSR	74	1 081	73	1 228
SRDWB	15	215	14	244
Averages (excluding September 1)				
TPD	2 156	5 964	332	*8 452*
PDSR (Ad.+Ny.)	260	1 739	181	*2 181*
SRDWB (Ad.+Ny.)	48	156	29	*233*

ad. = adults, Ny. = nymphs.

TABLE XV a

Monthly variation in soil water content (% oven dry weight), calculated as means of windward and leeward values of *Lygos, Thymelaea* and *Lycium* *

Month	Surface	Depth — 20 cm	— 50 cm
February 75	4.55	6.10	4.67
March	3.51	5.87	5.62
April	1.34	3.89	4.36
May	0.47	2.57	2.35
June	0.32	0.91	0.75
July	0.42	1.71	1.90
August	0.65	1.54	1.01
September 1	0.49	1.69	2.38
September 2	0.55	2.30	2.92
October	0.56	2.60	2.92

TABLE XV b

Averages of soil water content under shrubs

Depth	*Lygos*	*Thymelaea*	*Lycium*
Surface	1.37	0.90	1.32
— 20 cm	3.08	3.05	3.42
— 50 cm	2.76	3.02	3.20
Total average	2.40	2.32	2.65

* Six determinations for each month, except Aug. (one determination).

TABLE XVI

Rank correlation coefficient for sand roaches *(Heterogamia)* population density/ha and dry weight biomass (gm/ha) with soil water content at — 20 cm and — 50 cm

Population characteristic	Soil moisture at	
	— 20 cm	— 50 cm
Log population density of adult sand roaches/ha	0.74	0.80
Log dry weight biomass of adult sand roaches, gm/ha	0.67	0.75

For all four values, $p = 0.05$ to 0.01, $n = 7$.

DISCUSSION

A compendium of methods for the quantitative study of soil animals was published by IBP (PHILLIPSON, 1971), where 11 major groups and about 30 minor groups of soil-dwelling animals are discussed as regards their quantitative extraction from soils. Although several methods are known for extraction of soil animals, these methods usually apply to soils of temperate and humid regions in the countries where these methods have been developed. There are no common satisfactory methods, yet, specific for desert soils which present their own problems due to their dryness and non-cohesiveness, precluding the use of augers or coring tools. CROSSLEY *et all.* (1975) overcame this difficulty by irrigating the soil, before sampling with a coring tool for micro-arthropods, and using the Tullgren extraction method. The population density of the soil mesofauna of Egyptian desert soils seems to be too low to allow the use of core samplers and would require sampling from a much larger area and irrigation with large quantities of water and still the soil would not be wetted to the desired depths. Moreover, some species might move away from the water. Therefore, the sieving method as used in this study seems to be the best suited for the purposes of this investigation under the conditions obtaining in this particular environment.

Moisture and Temperature Factors.

The main conclusion obtained from population density figures and faunal breakdown percentages is that shrubs on the landward side and whose canopies touch the ground, such as *Lygos*, harbour more soil animals. RANWELL (1972), in his review of research on abiotic factors in maritime sand dune, cites examples showing that dune sand under plant cover may be 20° C cooler than bare sand at noon time, and that the temperature difference results in strong dew formation on the plant surfaces at night (RANWELL, 1972, p. 17). Whatever rainfall or moisture there is, it is held by the accumulated litter under the shrub and by the soil organic matter in the upper 10 cm layer more firmly than by bare sand. The water content of sand at depths between 60 and 90 cm is higher under plants. Absence of organic matter causes serious moisture deficiencies at the surface even if cover is provided. Moisture-laden air from the sea may be drawn to pore spaces of the sand or an upward movement of water vapour from cooler and moister deeper sand layers may occur (RANWELL, 1972, p. 157). In the present work, *Lycium* which is facing the sea, has a greater soil moisture content under its canopy (2.65 % on the average for the study period) than the other shrub species on the crest *(Thymelaea)* or landward *(Lygos)*, being 2.32 % and 2.40 % respectively (Tab. XV). The loose oolitic limestone grains of the littoral sand dune are known to allow vertical percolation of rain water so that underground water is available in fairly good quantities all year round. Relative humidity of the air increases in summer (Tab. I). ABD-EL-RAHMAN and SHARKAWY (1968) studied dew formation in the Burg-el-Arab area at a point about 7 km SE of the present study site, by the use of lysimeters 50 cm deep, filled with the natural soil core, embedded in the soil and placed in the open spaces as well as in shade of fruit trees. Their results show that a net gain of moisture took place into the soil in all months of their study period (Sept. 1961 - Jan. 1963, i.e. 17 months). It contributed sensibly to the soil moisture particularly during the dry period from March to September. For the whole year the average gain was 93.0 mm, i.e., about 62 % of the annual rainfall amount of 150 mm for that year. It has also been shown by these investigators that when the moisture gain from the atmosphere is relatively large enough to allow sensibly measurable increase in the moisture content of the superficial 0-2 cm layer of the soil, this water could : (a) percolate to deeper layers (— 10 cm) and (b) compensate for a greater amount of the water lost during daytime.

Another piece of research of more direct bearing to the present study is the hydroecological study of the sand dunes of Burg-el-Arab, at a site 3 km to the west of the present study site, by ABD-EL-RAHMAN *et all.* (1965). The moisture content of deep layers (depths of 25-50 and 50-75 cm) was less variable from February to September 1959 than in the topsoil. The lowest recorded value for the deeper layers was 2.5 % at 25-50 cm in August. This value increased to 3.2 % in September. The permanent wilting percentage for these two deeper layers were 2.07 (25-50 cm) and 2.32 (50-75 cm). The authors thus have shown that layers below 25 cm remained permanently wet during the dry season. Furthermore, they have shown, by measurements of soil moisture in the upper 2 cm layer at 3-hour intervals, from March to August, that soil moisture at the surface varies daily from a minimum in daytime to maximum before sunrise (between 4 and 7 a.m.). These variations are shown in Table XVII.

TABLE XVII

Variations in soil moisture content at the upper 2 cm layer from March to August 1959 (after ABD-EL-RAHMAN *et al.*, 1965), as % oven dry weight

Month	Minimum	Maximum	Gain
March	0.8	2.2	1.4
April	0.5	1.6	1.1
May	0.4	0.8	0.4
June	0.4	1.4	1.0
July	0.3	1.3	1.0
August	0.3	1.6	1.3

Since the permanent wilting percentage for this layer is 1.90, as determined by these authors, the maximum values attained in soil moisture content must be of significant importance for soil fauna active at this layer and at night time. This gain in soil moisture was found by these authors to be ineffective at the — 5 and — 10 cm layers.

Temperature measurements were made by the same authors at different depths from the surface down to 50 cm for the same period. They found that the range of temperature variation at the soil surface is much wider than at lower depths. The range of diurnal variations narrows with depth until it becomes negligible at — 50 cm. The range of variation of the upper soil layers is more pronounced in summer (22° C) than in winter (3° C). Since the authors also found a temperature gradient between the soil surface and the overlying air, they concluded that condensation of water vapour on the soil surface may take place from the air above as well as from the deeper soil layers. The temperature measurements of these authors show that a reversal of the temperature gradient from a hotter surface-cooler depth condition to a cooler surface-hotter depth condition occurs some time before 7 p.m. and is restored some time after 7 a.m. back to daytime conditions.

Total Population Density of Soil Mesofauna.

The overall population densities are comparable but lower than those obtained in other desert sites, undoubtedly because microarthropods (especially mites) were not found and were not collected in very large numbers in the present investigation. Population density estimates of desert sites in the US/IBP Desert Biome Program are still unpublished. At the Pawnee National Grassland site, Colorado, U. S. A., CROSSLEY et all. (1975) recorded a biomass grand mean of 413 mg/m^2 (dry weight) for the summer of 1970 in a range of values from 30 to 1400 mg/m^2, of which 50 % was due to Collembola and mites, and the other 50 % due to « other Insecta », but dominated by Homoptera. The average dry weight biomass of sand roaches alone in the present study is 1865 mg/m^2, with a range of values from 0 to 7085 mg/m^2. Although population density is not given in the study of CROSSLEY *et all.* (1975), it is expected that they would record high figures due to the small size of the micro-arthropods concerned. The highest population density figure recorded here is 489/m^2, but the total average is 51/m^2. Such a low level indicates the harsh natural and anthropogenic conditions prevailing in the Egyptian site. Perhaps the most severe manipulation is the quailtrapping practice which tends to offset the gains in population densities in summer due to the increase in soil moisture content from dew, as there is no significant change in population density from one month to the next, or from one season to the next. This kind of manipulation falls within the type of marginally exploited unmanaged natural ecosystems in the classification by GHABBOUR (1974).

Sand Roaches.

The positive correlation between population density of sand roaches and their dry weight biomass on one hand with soil moisture on the other hand (Tab. XVI) indicates that sand roaches are able to take advantage from gains in soil moisture content, even if it is relatively lower in summer than in winter. According to the work of ABD-EL-RAHMAN and SHARKAWY (1968), referred to above, there is a good chance of moisture gain from dew in the soil whenever relative humidity of the air exceeds 90 %, and this may continue for several hours during the night and occurs in most months of the year. The mean daily gain ranged between 0.2 and 0.7 mm in the open and between 0.1 and 0.4 mm in the shade of fruit trees. It is to be noted that desert shrubs with canopies touching the ground, as *Lygos* and *Lycium*, retain more moisture in the soil than a shrub with diffuse upright branches as *Thymelaea* (Tab. XV). It is possible that, since sand roach populations correlate so clearly with soil moisture fluctuations, they may behave here in a way comparable to the behaviour of the related *Arenivaga* sp. (later known as *A. investigata*) in the deserts of the southwestern United States. This species is able to absorb water vapour from relative humidities above 82.5 % after desiccation. This phenomenon obtains in the nymphs and adult females only (EDNEY, 1966). In field studies, this species was found to have access all year round to soil layers with relative humidities higher than 82 % (EDNEY *et all.*, 1974). These latter authors found that, throughout the year, it was always possible for *A. investigata* to reach a relative humidity of about 82 % by going down to — 45 cm in the sand (the insects were found at this level); consequently it would be possible for the sand roaches of Gharbaniat (if they have a similar physiology) to remain in positive water balance throughout the year in the littoral sand dune even if no free water is available. It is to be noted that the sand roach population at the Gharbaniat site correlates more strongly with soil moisture at — 50 cm than at — 20 cm. It can therefore be concluded that sand roaches here depend very much on the water vapour within the soil atmosphere to maintain their vital activities without interruption in summer. This may be supported by the fact that they are more abundant under *Lycium*, which is north-facing, and which is found to retain more moisture. Sand roaches inhabiting the littoral sand dune at Gharbaniat go deep down in daytime, thereby avoiding water loss and taking advantage from being surrounded by soil with a higher moisture content than at the surface. They go upwards at sunset to near the surface (the upper 0-2 cm layer) to feed on litter and/or to breed, thereby taking advantage of coolness and dew formation to prevent excessive water loss and, probably, to regain whatever moisture they may have lost during daytime and to store water for the next day. They thus adapt their activity rhythm to the daily cycle of temperature and moisture to the best of their advantage. As a matter of fact, sand roaches kept in the field station and in the laboratory were observed to be active usually between 8 p.m. and 6 a.m. approximately. *Arenivaga investigate* has also a similar diurnal rhythm observed in the southwestern United States (EDNEY *et all.*, 1974). It is thought by these authors that *A. investigata* reacts to a temperature gradient and probably also to a moisture gradient. The water metabolism of desert arthropods is discussed by SHAW and STOBBART (1972) who compare *Arenivaga* with other arthropods which have an impermeable cuticle.

The effect of seasonal variations in temperature, as opposed to diurnal variations, on the population density of *Heterogamia syriaca* at Gharbaniat, is not very much apparent. It is apparent to some degree, however, on the population density of soil mesofauna other than sand roaches, as can be seen from Fig. 2. From an initially high value in early February (12287/ha) the population density of soil mesofauna other than sand roaches drops to its lowest recorded value in the first week of March and then increases steadily with the gradual increase in temperature from March to early July in spite of the concomitant drying up of the soil. Then there is another drop during July and a new rise in late August and September with the gradual cooling after the August temperature and moisture variations; it is seen that the latter two factors do not have each a single absolute control. The high moisture of February is favourable for some species (e.g. isopods, *Agabiformes lentus*) in spite of the low temperature while the warmth of spring and summer is favourable for some other species in spite of the dryness. The rise in population density in spring and summer must also be correlated to the abundant food material becoming available to soil animals in these two seasons by the shedding of plant parts (leaves, flowers, seeds) and by the death of annual plants. But during July, the high temperature and dryness act together in decimating large numbers of soil mesofauna, when many species end the active stages of their life cycles and aestivate as eggs or pupae. In August and September the rise in moisture content of the soil again favours some species which resume an active life anew. In the June sampling, the most abundant species were the tenebrionid beatle *Stenosis torre-tassoi* Koch, the sand roach *Heterogamia syriaca* Sauss. and the tenebrionid *Dendarus piceus* Ol., in the same order. In the September 2 sampling, the most abundant species were *Stenosis torre-tassoi*, the ant *Camponotus maculatus* F., the heteropteran cydnid *Macroscytus brunneus* F. and the antlion *Cueta* sp., also in the same order.

It is interesting to note that the September disturbance for quail trapping reduced the population density of soil mesofauna (excluding sand roaches) to about one third of what it should be at the corresponding soil moisture (at —50 cm), that is, considering the population density/ha.

Ants.

A review of literature on the ants of Egypt (FINZI, 1936 and SANTSCHI, 1937) shows that at least 25 species and varieties should exist in the northwestern desert. Most collections, however, were made at Mariut station near Alexandria and only two collections were made at Hamman, where *Messor arenarius* was found in May and *Crematogaster inermis* in October. Collections reported in those two works were made during all months of the year except June and December. The type of habitat was not mentioned by the collectors, so the number of species and forms of ants should be smaller in any particular habitat (the littoral sand dune or the inland non-saline depression, for example). The minimum number of ant species and varieties, according to those authors, should be as follows :

January : 8 all from Alexandria
February : 2 from Maamura and Dakheila (Alexandria) and from Salloum
March : 8 from Mariut, 1 from Alexandria 10 from Mersa Matrouh and 7 from Salloum
April : 6 from Alexandria, 1 from Mersa Matrouh and 1 from Salloum
May : 1 from Hamman and 1 from Salloun
July : 1 from Mariut
August : 2 from Salloum
September : 1 from Alexandria and 1 from Mariut
October : 1 from Hammam
November : 1 from Alexandria and 3 from Mariut

Although such faunistic collections are only of a cursory nature, yet they show some trends. The month of highest number of species is March (it is also the month of most intensive collection). But our nest counts corroborate that ant activity is higher in winter and spring and lower in summer.

WILSON (1971) states that species of *Messor*, as well as a few *Monomorium* species, depend principally or entirely on seeds, which they store in their earthen nests in special granary cells, which in the case of *Monomorium salomonis*, may reach a depth of 6 metres. Ants with this kind of activity, says WILSON, are thus important agents in the dispersal of plants. Ants are the principal movers of the soil in deserts, and by moving seeds, enriching the soil, and attacking growing plants in a selective and patchy manner, ant colonies play a key role in determining the structure of plant communities in deserts.

Moisture and Temperature Effects.

The importance of moisture in starting and maintaining the process of litter breakdown in arid regions ecosystems cannot be overstressed. Firstly, water dissolves between 10 and 30 % of the substances in freshly fallen mesophytic leaves ; most soluble substances being leached rapidly out of litter. As litter decomposes, small organic and inorganic molecules are produced increasingly, these are exposed to further leaching (RICKLEFS, 1973). Secondly, decomposer animals can hardly obtain their water requirements from totally dry litter or soil ; moisture reaches a certain level specific for each animal. Rate of decomposition will thus depend primarily on moisture content of litter and soil, and will be modified by other factors such as lignin content of litter, amount and nature of obnoxious substances in litter, temperature and on age of litter (hence level of its decomposition).

Soils in desert ecosystems should be moist to a degree compatible with the activity of the local soil fauna at least in the rainy season. In the present study on the littoral sand dunes, a soil moisture at — 50 cm of at least 1.5-2 % is sufficient to maintain the activity of sand roaches, thus decomposition could proceed at an appreciable rate even during summer (in the absence of rain), because of gains in soil moisture from dew formation. Sand roaches, as can be seen from Figs. 2 and 3, depend very closely on soil moisture at the specified depth of — 50 cm. Not only does their population density follow variations in soil moisture at this depth, but also their reproduction and their dry weight biomass. Their reproduction in August followed a slight rise of moisture from about 1 % to about 2 %. Their dry weight biomass, following closely the moisture, shows that their feeding and food storing in their bodies proceed at rates closely following presence of soil moisture. This is similar to the case of two species of oligochaetes investigated by KHALAF EL-DUWEINI and GHABBOUR (1968). Dry weight of each of these two species *(Allolobophora caliginosa* and *Pheretima californica)* was maximum at the optimum soil water content (at which 100 % survival was recorded). Although gut contents were included in the dry weight calculations (as in the present investigation) it is possible to conclude that for both animal groups (earthworms and sand roaches) feeding is most active at the optimum soil moisture level. In the case of sand roaches, this optimum moisture level is about 5.5 % again at — 50 cm, as can be seen from Figs. 2 and 3. Nevertheless, small gains of moisture in the soil, even at much lower levels than 5.5 % are highly effective, since the small rise in July from 1 to 2 % moisture produced a 267 % rise in dry weight biomass/ha, in addition to a new generation of nymphs whose dry weight biomass was 23 % that of the original adult population, i.e. there was a total gain of 300 % in dry weight biomass. All this gain undoubtedly originating from litter breakdown. This clearly shows the maritime effect on the littoral sand dune ecosystem.

The combined effects of moisture and temperature on the diurnal activity of sand roaches can be understood when we consider the results of measurements of these two factors published by ABD-EL-RAHMAN *et all.* (1965). As was mentioned above, conditions at the soil surface become somewhat favourable around 7 p.m. when dew starts to form and temperature inversion between upper and deeper soil layers occurs. The temperature inversion may be the factor inducing sand roaches to move upwards. On the other hand, the reversal of the temperature inversion after 7 a.m. may not be the inducing factor for their movement downwards because their downward movement and their torpor occurs about 1 hour earlier and coincides with the drop in soil surface moisture content at about 6-7 a.m. (as can be seen from the measurements of ABD-EL-RAHMAN *et all.* 1965). However, the reversal of the temperature gradient in the morning is late in January and February and may occur as late as 9-10 a.m. when the soil surface is only 1° C warmer than the deeper layers, and in fact sand roaches have been observed to remain at the surface to as late as 9-10 a.m. (under the shrubs) when sampled in January. It should be recalled, then that soil surface does not dry up to a level incompatible with the life processes of sand roaches, that evaporation at 10 a.m. in January (as measured by ABD-EL-RAHMAN *et all.*, 1965) is at a relatively low value of about 0.3 mm/hr, and that sand roaches may require some heat absorption as long as they do not lose water specially if this will also help them to stretch their feeding time. January must be considered a favourable month since there is a reproduction period in that month.

It may be concluded, therefore, that soil moisture is the most effective factor controlling population density and diurnal activity of sand roaches in the

Gharbaniat site, and that temperature comes into play when moisture is not limiting.

It will be useful at this stage to draw up a water balance sheet for the littoral sand dune habitat based on data provided by ABD-EL-RAHMAN *et all* (1965) and ABD-EL-RAHMAN and SHARKAWY (1968), even tentatively, to compare it with actual observations on the water resources of the habitat and the distribution of soil mesofauna. According to ABD-EL-RAHMAN *et all.* (1965) the water output by the total vegetation covering 100 m² and dominated by *Ammophila arenaria* (its total fresh weight being 90 % of the total fresh weight of all species and its contribution to the total water loss by transpiration bein 90 % also in May) — varied between 25 Kg./day in February and 90 Kg./day in May. Evaporative power of the air varied between 0.1 mm/hr in February and 1.0 mm/hr in summer months. Since no values were given for October, November and December, intermediate values for these months are calculated here by intrapolation and included in the yearly total. Hence, the yearly total water output by an area of 100 m² covered by vegetation dominated by *Ammophila* would be 35970 litre, that is the equivalent of 360 mm rainfall/year. The evaporative power of the air calculated from actual field measurements of these authors and considering 12 hr/day would be 2884 mm/year; the Piche evaporation data of Burg-el-Arab (calculated from Table 1) would give 2941 mm/year. If we assume that at least 93.0 mm/year is gained from dew formation, as calculated for the period 1961-1963 by ABD-EL-RAHMAN and SHARKAWY (1968) and allow for a higher figure at the littoral sand dune, especially for the north-facing slope, this still would not account for the water loss, unless rainfall is around 250 mm/year, which is not very common. *Ammophila* roots penetrate to a depth of 160 cm and can absorb water from the deep permanently wet layer, so that this plant can use up all the available surface water and compensate for the difference from water reserves in the deeper layers. The environment of the *Ammophila* root system thus appears very demanding in water resources and soil moisture must be exhausted in *Ammophila* stands, which would be competing severely for moisture with any soil animals that may need to absorb water vapour from subsaturated atmospheres, such as sand roaches. But if *Ammophila* is not present, it is as if 320 mm rainfall per year is made available to the soil fauna, particularly to the highly moisture-dependent sand roaches. This is the amount transpired by *Ammophila* alone. This may explain, to some extent at least, why sand roaches are more abundant under the seaward *Lycium* in an *Ammophila*-dominated or -codominated stand but are absent under *Ammophila* itself. This does not mean, however, that no soil mesofauna exist under *Ammophila*, because KÜHNELT (pers. comm.) found the carabid *Cymindis* and noctuid larvae in this situation, during his stay in 1956. The noctuid larva feeds on leaves of *Pancratium* and is partly carnivorous.

CONCLUSIONS

The sampling method used in this study, by sieving soil from under the canopies of major shrubs, proved adequate in discerning patterns of distribution of soil mesofauna both in space and time during the study period from February to September 1975. These patterns became more discernible when population densities calculated per square metre under each shrub species was extrapolated to population densities per hectare through multiplying by the known absolute percentage cover for each shrub species. Of the three shrub species chosen, the shrub *Lygos*, found mostly on the south-facing landward slope of the littoral sand dune, harbours a higher density of soil mesofauna, while the shrub *Lycium*, found mostly on the north-facing seaward slope and exposed to winds, but also to moisture, harbours a higher density of sand roaches. The shrub *Thymelaea*, with diffuse upright branches, unlike *Lygos* and *Lycium* whose branches touch the ground, and with a distribution pattern mostly localised on the crest of the dune, thereby exposed to wind but relatively derpvied of moisture, harbours an intermediate population density which is significantly lower than under *Lygos* or *Lycium*. Nevertheless, because *Thymelaea* has a relatively high percentage cover (1.36) as compared to *Lygos* (0.26) and *Lycium* (0.11), the population of soil mesofauna it harbours is larger in absolute terms and has a greater weight in the extrapolated population densities per hectare. From these extrapolations it was possible to discern the following relationships:

1. Although there were no statistically significant differences in population densities of total mesofauna (per square metre) from one month to the other or from season to season and even between disturbed and undisturbed soils in September (for quail trapping), a strong positive correlation was found between population densities of adult sand roaches/ha and soil moisture at — 50 cm. As regards other groups of soil mesofauna excepting sand roaches, such a direct relationship could not be discerned because of the heterogeneous nature of such a lumping, since the abundant species naturally differ from one month to the next. However, it was still possible to find out that there is a mutual interplay between the effects of temperature and soil moisture. The rise of temperature in spring favours a gradual increase in population density although the soil is drying up, but further warming and dryness are unfavourable in summer. The slight rise in soil moisture because of dew formation in late summer again favours a second increase in population density although temperature is around its maximum. The high population density in February (associated with relatively high soil moisture) is due to the presence of large numbers of young isopods of the species *Agabiformis lentus* (B.L.). In June and September, the dominant species was the tenebrionid be~~a~~etle *Stenosis torre-tassoi* Koch, seconded in June by *Dendarus piceus* Ol. and in September by the ant *Camponotus maculatus* F., its myrmeleonid predator *Cueta* sp. and the cydnid *Macroscytus brunneus* F.

2. Calculations of dry weight biomass of sand roaches show that it changes from one month to the next. It is strongly correlated with soil moisture at — 50 cm, thus showing the same phenomenon as was previously shown for earthworms which are very strongly dependent on soil moisture levels for maintaining their vital activities of feeding and breeding and which lose and gain water from the soil through their integument. *Arenivaga investigata* is known to absorb water vapour from unsaturated air. It is very probable that *Heterogamia* has the same ability since it can profit from slight increases in soil moisture in summer to increase in population density and in dry weight biomass, and also to have a second reproduction period in August.

3. Although no statistically significant difference was found between disturbed and undisturbed soils in September, except for sand roaches by the X^2 test, such a difference was apparent with extrapolations. It was found that sand roach population was reduced by 34 % and other soil mesofauna

populations by 70 %, from what they should have been at the particular soil moisture. Moreover, the presence of large numbers of ants in the subsequent sampling may be an artefact caused by the disturbance. This disturbance also caused a lowering of soil moisture content at the surface and — 20 cm and a slight elevation at — 50 cm.

SUMMARY

The present paper is the first of a series reporting investigations into the ecology of soil fauna in the northwestern Mediterranean coastal desert region of Egypt. This area was productive in Graeco-Roman times but is now producing at less than the desired rate. Several important development projects are planned for the region to increase its productivity and its carrying capacity, mainly by irrigation agriculture, industry and tourism. It may be possible, by using the proper management techniques, to utilize soil fauna to increase the rate of litter and organic matter decomposition, thereby helping to recycle nutrients and reduce cost of fertilizers — if the conditions of life of soil fauna populations in deserts of this region are well understood.

The area receives an average 150-180 mm rainfall per year (in winter). The littoral sand dune habitat is one of the major four habitats that may be distinguished in the region. It is formed of loose oolitic limestone and dominated by *Ammophila arenaria* and some other associates. Samples were taken by sieving soil from under the canopy of the three major shrub species : *Lygos raetam, Thymelaea hirsuta* and *Lycium europaeum.* Samples were taken once every month from January 1975 to September 1975.

There was no significant difference in population density/m^2 of mesofauna through time, even in summer. There was strong correlation between sand roach population density extrapolated per hectare and their dry weight biomass with soil moisture at a depth of — 50 cm. Since sand roaches consitute a considerable proportion of the fauna, changes in their population density are more marked than changes in other groups. Soil moisture at — 50 cm increased during the summer months and sand roach population increased concomitantly, thereby accounting for the absence of significant variations in total population density of soil mesofauna which would be expected to occur in summer.

Activity of ants in nest building is less marked in summer.

SOMMAIRE

Ce travail est le premier d'une série qui donnerait des renseignements sur les recherches d'écologie de la faune du sol à la côte méditerranéenne au nord-ouest de l'Égypte. Cette région, jadis d'une haute productivité à l'époque gréco-romaine, puisque les poètes latins s'enchantaient de ses vins, est à présent appauvrie, en premier ordre à cause de négligence, depuis le XI^e siècle de notre ère. Plusieurs projets importants pour le développement des ressources de cette région sont en cours de planification, avec le but d'augmenter sa productivité et sa capacité de nourrir et d'héberger une certaine partie de la population d'Égypte. Ces projets de développement comptent l'agriculture par l'irrigation en utilisant l'eau du Nil ou l'eau obtenue d'un réacteur nucléaire qui sera construit à Sidi-Kreir, l'industrie par l'énergie hydro-électrique obtenue d'une chute artifi-

cielle prévue à la dépression de Qattarah, et le tourisme. Il sera peut-être possible, en utilisant les techniques convenables d'aménagement, de profiter de la faune du sol pour accélérer le processus de la décomposition de la litière et de la matière organique dans le sol, ainsi peut-on réduire les coûts d'engrais si on comprend bien les conditions de vie de la faune du sol dans les déserts de cette région.

Cette région reçoit entre 150 et 180 mm de pluie par an (en hiver). L'habitat de la dune calcaire littorale est un des quatre habitats importants qu'on peut distinguer dans cette région. Le sol y est composé de grosses graines de calcaire oolitique non-consolidées. La végétation dominante est celle dominée par *Ammophila arenaria* et ses associées, surtout au bord nord de la dune. Les prélèvements étaient faits en échantillonnant le sol entier sous trois espèces d'arbustes : *Lygos raetam*, *Thymelaea hirsuta*, et *Lycium europaeum*. Le sol était passé dans un tamis qui permet le passage de la microfaune (protozoaires, nématodes et la plupart des acariens) et doit garder la mésofaune. L'échantillonnage était fait une fois par mois du mois de janvier 1975 au mois de septembre 1975.

La densité de la mésofaune calculée par m^2 n'a pas montré de différences significatives avec le temps, même pas en été. Il y avait une forte corrélation entre la densité des cafards de sable/ha et leur biomasse d'une part et la teneur du sol en eau à une profondeur de 50 cm d'autre part. Comme les cafards de sable étaient un élément important de la mésofaune, leur densité (variant avec la teneur en eau à cette profondeur) a masqué les variations en densité des groupes moins importants. La teneur du sol en eau à —50 cm s'élevait depuis juillet, ainsi s'explique l'absence de différences significatives en densité de la mésofaune totale durant l'été.

L'activité des fourmis était moins marquée en été qu'en hiver.

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